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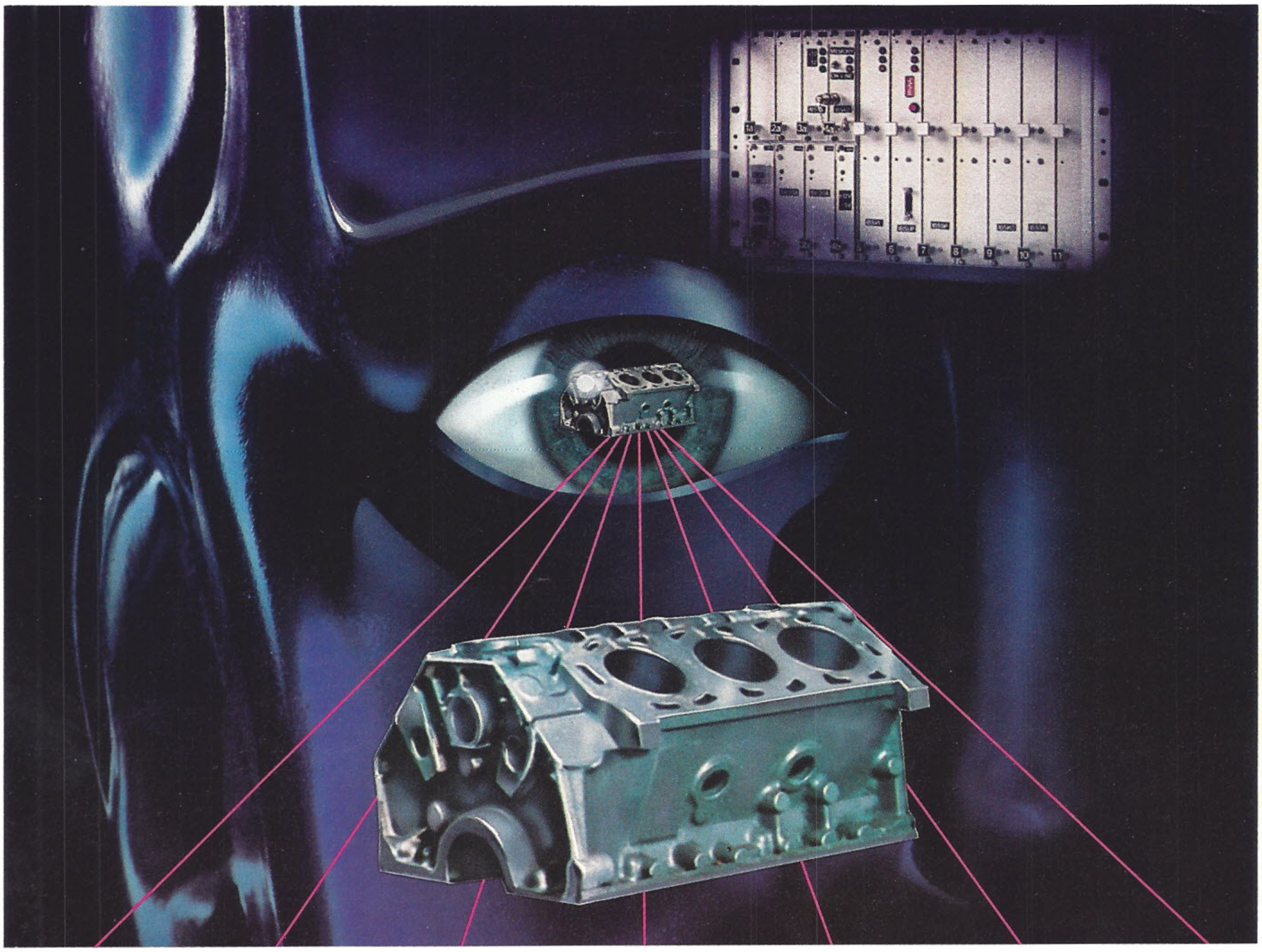
ROBOTICS ENGINEERING

THE JOURNAL OF INTELLIGENT MACHINES

Sensors in Robotics

Automated Inspection Systems



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ROBOTICS ENGINEERING

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EDITORIAL

FEATURES

DEPARTMENTS

About the cover: This month's cover photo, provided by Perceptron, Inc., is of a flexible measurement system as used in the door assembly process at an automotive plant. The system is explained in an article that begins on page 12.

High Technology in the 1980s

A Guest Editorial by
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The 1980s have witnessed a spectacular burst of development in high technology. This is the decade in which the space shuttle took off. Computers entered the home. GE announced the Factory of the Future. And robots, of course, were central to this vision. Miraculous reports reached us of unmanned production at the foot of Mount Fuji. We were told to "automate or evaporate" and many of us heeded the call.

Now, less than 10 years later, the space shuttle has blown up. The home computer is a bust. The Factory of the Future is still in the future, and, in the words of GM President Roger Smith, we are facing a "technology backlash." GM has slashed entire programs (e.g., GM 80) and cut back severely on automation projects, and what's bad for GM is bad for the U.S. The industry is reeling. The term "high tech" has fallen into disrepute.

Why has this happened in so short a period of time? Why has it happened at all?

The answer to these questions appears to lie more in the realm of human psychology than in the technology itself, or even its implementation; the answer reflects unrealistic expectations and poor communication.

Part of the blame undoubtedly lies with the industry. The term "robotics" conjures up visions of science fiction and Saturday morning TV cartoons. The technology has not yet lived up to its promise. Some deliveries have been late and full of bugs.

Responsibility rests equally with the management that acquired the technology. They took a calculated risk on unfamiliar technology. One normally expects startup problems with totally new technology; some of it will work and some of it will have bugs. Which is exactly what happened in the robotics field. Why the backlash?

Apparently, some people were hoping the new technology would do more than improve the production process, that it would *erase* major problems that plague U.S. manufacturing in terms of labor costs, productivity, and product quality. They were ready to believe that a solution to these problems could be bought off the shelf—and plugged in! And they have been frustrated by the results.

So now we are experiencing a mid-course correction. Robotics and high tech are no longer the glamour industries they once were, and others, like biotechnology, have taken their places. But all is not gloom and doom. A unique opportunity has presented itself. Manufacturing management is licking its wounds and scaling down its expectations. Now is the time to make the robot what it should have been all along—*the workhorse of industry*.

What we need now is summed up in the name of this journal: *Robotics Engineering*. What we need is good, solid engineering. The kind of engineering that took the I-beam and made the skyscraper. The kind of engineering that took the internal combustion engine and made everything from the Model-T to the Corvette. We need engineering that sees the robot as a tool and not as an end in itself. Along with this engineering, we need open, honest communications. So that all participants, from management down to machine operators and outside contractors, understand the goals of the project, and their part in its implementation.

Instead of seeing robotics as a way to avoid employee involvement—by avoiding employees—it must be recognized that, paradoxically, even more involvement is required to make the leap from conventional manufacturing to high-tech manufacturing. We need to commit more resources than ever to communication and motivation of the workforce, especially in debugging the technology.

With this kind of commitment, there is nothing that can stop U.S. high-tech industry, neither foreign competition nor temporary technical setbacks. We can emerge from the current backlash more mature, more efficient, and more competitive than ever.

From an historical perspective, the 1980s will be seen as the decade that U.S. technology got its second wind. ■

Calendar

SEPTEMBER

22–23. Motion Control Systems Seminar. Hilton at Colonial Hotel, Wakefield, MA. Contact: Seminar Registration, Electronic Motion Control Association, 230 N. Michigan Ave., Suite 1200, Chicago, IL 60601, telephone (312) 372-9800.

22–24. 1986 World Congress on the Human Aspects of Automation. Hotel Queen Mary, Long Beach, CA. Contact: Public Relations Dept., Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

22–25. Vision West at Ultratech. Long Beach Convention Center, Long Beach, CA. Contact: Gregg Balko, Technical Activities Department, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 368.

23–25. Artificial Intelligence and Advanced Computer Technology Conference/Exhibition. Rhein-Main Halle, Wiesbaden, West Germany. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

29–1 October. International Electronics Assembly Conference. Royal Sonesta Hotel, Boston, MA. Contact: Conference Dept., Institute of Industrial Engineers, 25 Technology Park/Atlanta, Norcross, GA 30092, telephone (404) 449-0460.

29–2 October. International Symposium on Industrial Robots (ISIR). Brussels Exhibition Centre, Brussels, Belgium. Contact: Brussels International Trade Fair, Place de Belgique-Belgieplein, B-1020 Brussels, Belgium, telephone 32-2-478.48.60.

30–2 October. Automated Design and Engineering for Electronics East. World Trade Center, Boston, MA. Contact: Banner & Greif, Ltd., 110 E. 42nd St., New York, NY 10017, telephone (212) 687-7730.

OCTOBER

2–3. Integrating CAD/CAM/CAE/CIM Into Your Organization: Issues, Pitfalls, Payback. Boston, MA. Contact: Joella Nelke, Seminar Mgr., Technology and Business Communications, Inc., 730 Boston Post Rd., PO Box 915, Sudbury, MA 01776, telephone (617) 443-4671. (To be repeated **9–10 October** in St. Louis, MO; **16–17 October** in Orlando, FL; and **30–31 October** in Los Angeles, CA.)

13–15. Stepping Motor Workshop. Howard Johnson Motor Inn, Portsmouth, NH. Contact: Mrs. Lee Wilhelm, University of New Hampshire, The Consulting Center, Horton Social Science Center, Durham, NH 03824, telephone (603) 862-3750.

20–21. Speech Based Systems for Industrial Applications. Essex House Hotel, New York, NY. Contact: Margo Kelly, Media Dimensions, Inc., 42 E. 23rd St., New York, NY 10010, telephone (212) 533-3943 or (212) 533-7483.

21–22. Selecting and Implementing an Automated Process Planning System. Contact: Nancy Loerch, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 386.

22–24. Fall National Plant Engineering & Maintenance Show and Conference. Georgia World Congress Center, Atlanta, GA. Contact: Show Manager, Fall National Plant Engineering & Maintenance Show,

999 Summer St., Stamford, CT 06905, telephone (203) 964-8287.

27–30. ATE Silicon Valley '86. Santa Clara Convention Center, Santa Clara, CA. Contact: Registrar, MG Expositions Group, 1050 Commonwealth Ave., Boston, MA 02215, telephone (800) 223-7126 or (617) 232-5470.

27–30. SYSTEC '86. Munich Trade Fair Centre, West Germany. Contact: Kallman Associates, Gerald G. Kallman, President, Five Maple Court, Ridgewood, NJ 07450-4431, telephone (201) 652-7070.

27–31. SATECH '86. Boston Park Plaza Hotel, Boston, MA. Contact: Intertec Communications, Inc., 2472 Eastman Ave., No. 34, Ventura, CA 93003, telephone (805) 658-0933.

28–29. Justifying Automation: A Survival Strategy for the Coming Decade. Holiday Inn, Ann Arbor, MI. Contact: Steve Trombino, Robotic Industries Association, 900 Victors Way, PO Box 3724, Ann Arbor, MI 48106, telephone (313) 994-6088.

28–30. Simulation and Computer Graphics: Design Tools for Effective Robot Applications. AMS Manufacturing Technology Institute, Norcross, GA. Contact: Mary Dombrowski, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 392.

NOVEMBER

3–6. Automated Manufacturing Exhibition and Conference. Greenville, SC. Contact: Scott Regan, PO Box 5616, Greenville, SC 29606-5616, telephone (803) 242-3170.

3–6. Electronic Imaging '86. Sheraton-Boston Hotel, Boston, MA. Contact: Registrar, EI '86 Conference, MG Expositions Group, 1050 Commonwealth Ave., Boston, MA 02215, telephone (800) 223-7126.

4–6. Winter National Plant Engineering & Maintenance Show and Conference. Anaheim Convention Center, Anaheim, CA. Contact: Show Manager, Winter National Plant Engineering & Maintenance Show, 999 Summer St., Stamford, CT 06905, telephone (203) 964-0000.

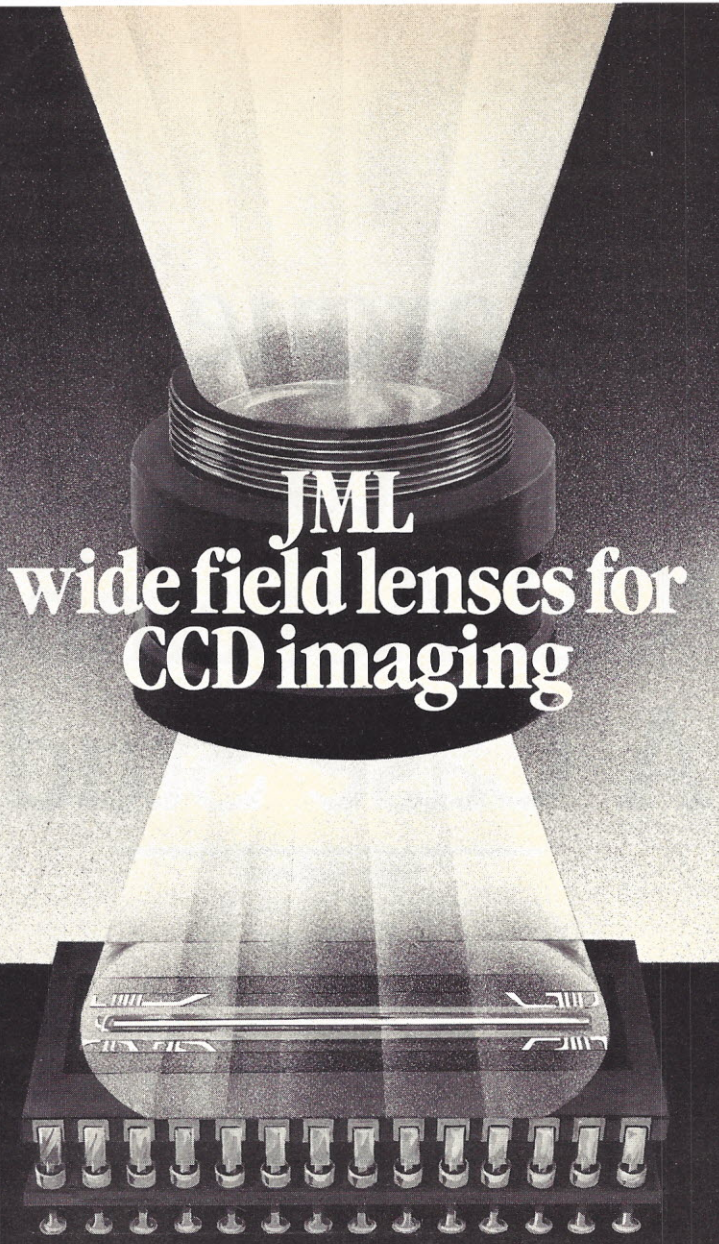
5–7. CAD/CAM/CIM Management: Today's Issues. (Computer Science Engineering Short Course) UCLA Extension Bldg., 10995 LeConte, Los Angeles, CA. Contact: UCLA Extension, PO Box 24901, Los Angeles, CA 90024, telephone (213) 825-3344.

10–12. Applied Robotics and Design Automation Conference. St. Louis Sheraton, St. Louis, MO. Contact: Oklahoma State University, Engineering Extension Office, Room 512, Engineering North, Stillwater, OK 74078, telephone (405) 624-5146.

11–12. Automated Inspection in Food Processing. Chicago, IL. Contact: Joanne Rogers, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 399.

11–14. AUTOFACT '86 Conference and Exposition. Cobo Hall, Detroit, MI. Contact: CASA/SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

28–30. Forth Modification Laboratory. Asilomar Conference Grounds, Pacific Grove, CA. Contact: FORTH Interest Group, PO Box 8231, San Jose, CA 95155, telephone (408) 277-0668.



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Circle 46

Force/Torque Sensing in Automated PCB Assembly: A Case Study

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The assembly of printed circuit boards typically includes the insertion of a family of components that are termed "odd-form" or "non-standard." These components include devices such as transformers, relays, large radial capacitors, connectors, switches, transistors, and a host of others whose unique body shapes, method of packaging, and low volume make the development of dedicated automatic insertion equipment economically unfeasible. Therefore, most of these non-standard components continue to be assembled manually, while the majority of the standard components, such as axial resistors and dual in-line packages, are assembled automatically at high speeds. Although odd components constitute a minor percentage of the total component population, their assembly often accounts for most of the direct labor input.

Electronic manufacturers have recognized this potential for direct labor reduction and have targeted the odd component insertion as a prime candidate for robotic assembly. Much development has taken place throughout the industry over the past several years. As a result, numerous non-standard component assembly systems have been installed in production environments. This technology is now accepted as an alternative to manual assembly where it can be economically justified.

One weakness of many of the early robotic insertion systems was that they used the dead reckoning technique and assembled parts "blindly." The hit rate or insertion quality level was highly dependent on the quality of the parts, the lead-forming process, and a number of other system parameters. As a result, the performance of these robotic systems fell short of expectations when installed in a factory where parts vary from lot to lot. It has become evident, through the experience gained from these early systems, that insertion verification is necessary. Let us examine a non-standard component assembly application where a commercial force/torque sensor has been employed to detect mis-insertions.

APPLICATION BACKGROUND

Northern Telecom, Inc. produces the DMS-10 digital switch in its Plaza facility located in Research Triangle Park, North Carolina. The DMS-10 switch is designed to be used by rural telephone companies, and it can be configured to match the needs of a particular customer. This design flexibility has created a high model mix situation in production, which complicates automation efforts.

The company installed a five-robot assembly line in January, 1985 to insert

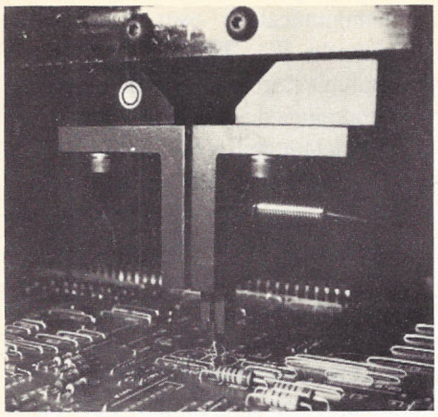


Photo 1. The robot takes a transistor from the registration die, used to compensate for lead spacing variability, and attempts to place it into a line card.

non-standard components into its DMS-10 line cards. This assembly system has been termed the "Flexline," for it was designed to assemble the numerous models of line cards in lot sizes of one. The Flexline employs Seiko RT-3000 robots interfaced to a Hirata stop-station conveyor line. Each station on the line is composed of a set of parts presentation equipment and a cell controller (IBM PC and an Allen-Bradley PLC). The Flexline augments an extensive array of automatic insertion equipment used to assemble the standard components.

DESCRIPTION OF THE TASK

The first station on the Flexline inserts 8 to 22 TO-92 transistors per line card, depending on the particular model being run. The transistors are processed in an off-line lead-forming operation to conform to the TO-5 lead spacing with a snap-in lead form. They are then transferred to the robot station and loaded into one of three feeder bowls according to their part number. The quality of the lead forming varies with the condition of the forming tool; the snap-in height and lead spacing are therefore variable. In addition, the process of bowl feeding adversely affects the condition of the TO-92's thin leads. To compensate for the lead-spacing variability, a registration die is used prior to insertion. The robot transfers the transistor from the feeder to the registration die to align the leads. It then removes the part from the die, positions the part over the line card, and attempts the insertion (Photo 1).

Most of the components that are properly inserted into the registration die are inserted into the line card without a jam. However, there are some that miss due to tolerance build-up of robot positioning, board registration, and errors in hole size and location. Due to the off-line lead forming and bowl feeding process, one or more leads will occasionally miss the holes in the registration die. This situation must be reliably detected, or a mis-insertion will definitely occur at the line card.

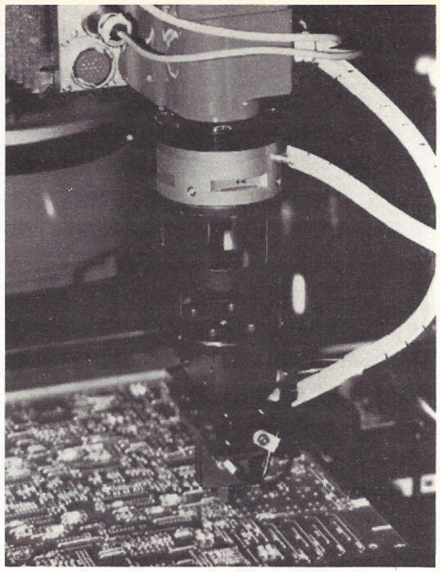


Photo 2. The robot's modified gripper is outfitted with a spacer, designed to be light and stiff to minimize the rising and settling time of the force/ torque sensor.

Problems with Lead Jam Detection. A lead jam sensing mechanism was designed into the original system. It consisted of a pair of precision ball slides sandwiched between the gripper finger mountings and the finger tooling. The ball slides allowed the part to travel upward a fraction of an inch if a jam occurred. This upward travel was detected by a proximity sensor mounted to the gripper, which in turn signaled the robot that a jam had occurred. This simple mechanism proved ineffective in production—it was not sensitive enough to detect a single lead's being out of alignment. In addition, the force threshold indicating a jam condition was not repeatable. Consequently, many mis-insertions went undetected until final inspection, adversely affecting the product quality. A solution had to be found.

Problems with Part Snap-In. As noted, the TO-92 transistor leads were preformed to a "snap-in" TO-5 configuration. The stand-off height of the transistors is inconsistent because of variances in the lead-forming dies. Therefore, inserting the transistors to a fixed height does not guarantee that the part will be snapped in. Inserting to a specified force threshold is preferred over the fixed-height method in this case. The technique requires an additional force threshold to be set higher than the jam force threshold, and the original jam detection sensor could not perform this service.

Solution to Jam Detection and Snap-In Problems. Alternatives to the original jam detection sensor were investigated. They included single-axis load cells, precision switches, verification of the leads in the registration die, LVDT sensors in the existing fingers, and a Lord six-component force/ torque sensor system. The Lord sensor was chosen for a number of reasons:

- It is overload protected to guard the transducer element from overload damage caused by accidental collisions.
- It is easily interfaced both mechanically and electrically to the existing robot system.
- The Lord system includes simple input/output thresholding software for communication over the robot's discrete I/O. This software allows multiple trip force conditions to be programmed and easily modified during debug and production.
- The system has additional force and torque capabilities other than "z" axis sensing for use in future applications.

Sensor Integration. The Lord F/T 15/50 force/torque sensing system was selected for the transistor insertion application. The 15/50 unit has a ± 15 lb., ± 50 in.-lb. capacity with a resolution of 0.2 oz. The system is composed of three elements: transducer, preprocessor, and the sensor controller. The transducer consists of a strain star element that has been instrumented with an array of silicon strain gauges. The strain star is housed within the transducer body, which includes four overload pins that engage after the rated load has been exceeded. Also contained within the transducer body is an electronic circuit that performs signal conditioning. The signal from the transducer is fed over a cable to a preprocessor unit mounted on the robot arm. This preprocessor digitizes the strain gauge outputs, serializes the data, and transmits it to the system controller. The system controller can be mounted 100 feet from the robot; it converts the individual strain gauge readings

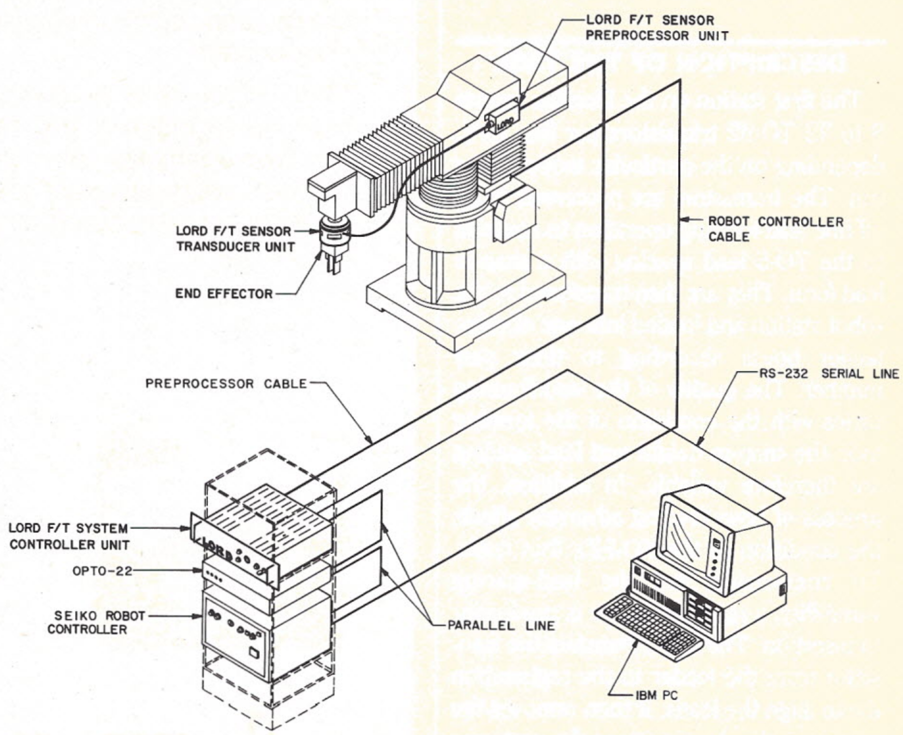


Figure 1. The sensor is interfaced to a Seiko RT-3000 robot over the parallel I/O using solid-state relays as a protective buffer.

into usable force and torque data and also interfaces the sensor with other equipment over its serial and parallel ports.

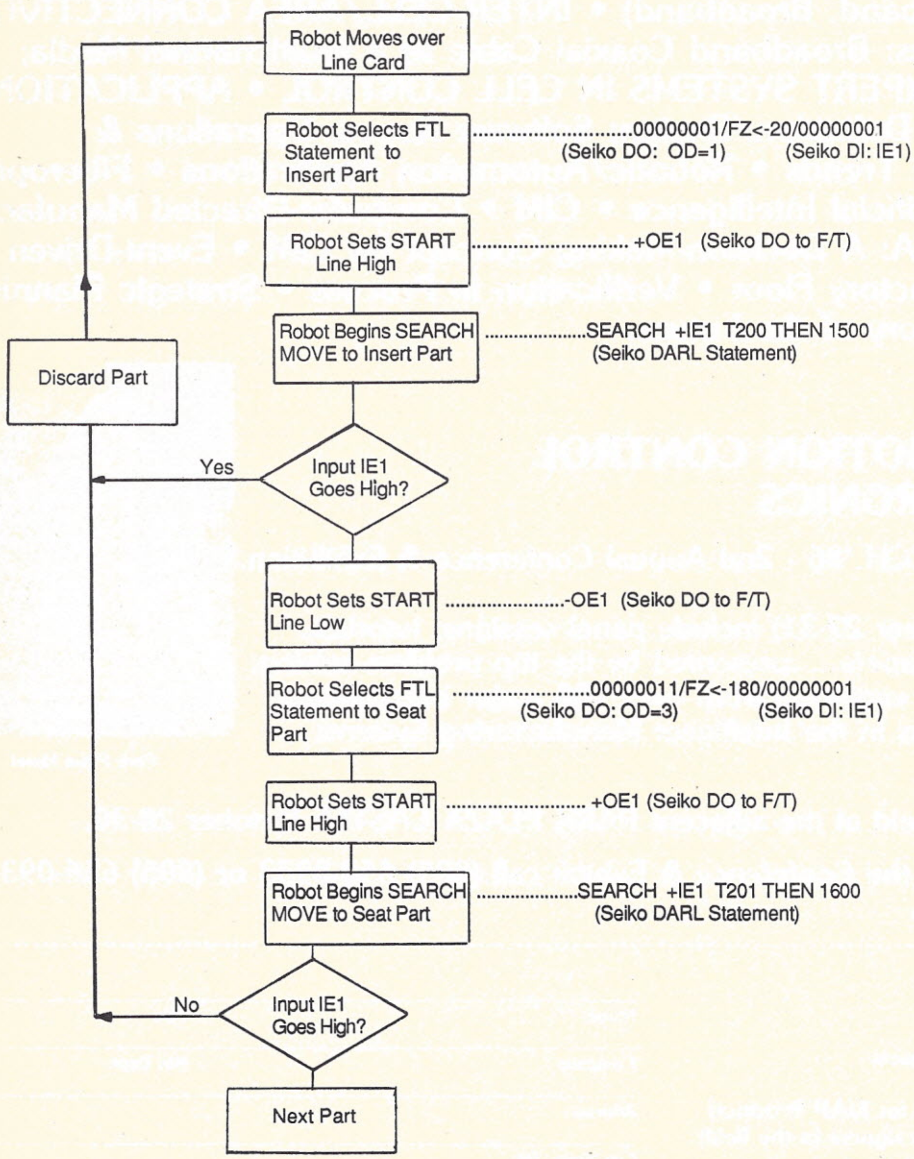
Interfacing the Sensor to the Robot. When the original parallel gripper was replaced by a smaller unit, a spacer was needed to match the length of the original gripper (Photo 2). This spacer was designed to be light and stiff to minimize the rise and settling time of the force/torque sensor. The sensor was interfaced to the Seiko RT-3000 over the parallel I/O using OPTO-22 solid-state relays as a protective buffer (Figure 1).

The Lord FTL language, resident on the F/T controller, was used to program the force thresholds that are monitored during the insertion and seating operations. It is a simple I/O language that allows the user to specify an 8-bit input code, a set of threshold conditions, and a binary output code. A total of 191 different FTL statements can be specified. The following parallel I/O lines were used for communication in FTL:

- Two robot output lines are used to select three different FTL statements (01, 10, 11). Each of the three FTL statements has a "z" force threshold specified for a particular task, e.g., seating and jam forces.
- One output from the sensor is interfaced to a single robot input to act as an interrupt to the robot motion. This line is driven high by the sensor when the threshold specified in the FTL statement becomes true. This interrupt input is specified in the Seiko SEARCH statement (Diagram 1).
- The START handshake line is interfaced to a robot output. The robot drives this signal high after it has selected the appropriate FTL statement for the task at hand. The START line initiates the FTL threshold evaluation process.

In addition to the parallel interface, the Lord sensor was interfaced to the IBM PC cell controller over the RS-232 port. The IBM PC is used as a programming terminal to specify the FTL threshold conditions. During operation, the IBM PC transmits the bias command to the sensor controller once each assembly cycle. The command nulls out any force and torque loadings caused by air lines, gripper weight, and cables.

Diagram 1
Robot-F/T Sensor Interaction



RESULTS

The installation of the Lord F/T sensor resulted in an improvement of insertion efficiency from 90 to 99.9 percent, based on a sample of 1000 line cards. This first production application of the F/T sensor also provided valuable information on ways to enhance its performance. Several problem areas were identified and the solutions incorporated into the standard sensor. For example, the vibrations generated by feeder bowls, conveyors, and the servo-hunting of the Seiko robot reduced the usable low-level sensitivity of the Lord sensor to 10 oz. A 10 oz. threshold is adequate for detecting most mis-insertions, but a level of 3 to 4 oz. is required for a searching routine to locate the missed holes. The lower threshold, by reducing the chances of the transistor's leads being bent in a jam, made the search routine worth attempting. Incorporating a low-pass analog filter in the transducer body resolved the problems with the vibrational noise generated by the ancillary equipment, improving the usable low-level sensitivity ten-fold—to 1 oz.

Another problem required a software solution. The sensor was biased by the IBM PC via the serial port once for every line card assembly cycle. This process required a delay of four seconds to ensure

that the command was processed. The need for such a delay arose from inefficiencies in the workcell control heirarchy and was not related to the sensor itself. The problem was solved by upgrading the software, allowing the Seiko robot to bias the sensor directly over the parallel port.

Finally, the transducer cable was first hardwired into the housing without strain relief. After seven months of operation, the cable frayed and failed and the sensor was replaced with the enhanced version that included a strain-relieved transducer cable with connectors at both ends.

FUTURE ENHANCEMENTS AND APPLICATIONS

The Lord F/T sensor was used primarily for "z" axis sensing. Future efforts will concentrate on using the other force and torque components to perform the following tasks:

- **Lead Presence Detection.** Laboratory experiments have demonstrated the Lord sensor's ability to verify the presence of all three transistor leads. Torque levels are monitored as the robot displaces the transistor body a fraction of a millimeter in opposing directions while the leads are contained within the registration die.
- **Opening Component Drawers.** Force and torque components will be used to verify that a parts drawer has been grasped and when its opening limit has been reached.
- **Searching for Parts in Trays.** Force and torque components will be used to detect the presence and location of a part in a tray prior to the robot's grasping it.

FOR FURTHER READING

1. Hoffman, B.D., et al. "Vibratory Insertion Process: A New Approach to Non-Standard Component Insertion," *SME Robots 8 Conference Proceedings*, June 1984, pp. 8.2–8.3.
2. *Lord F/T Sensor Installation and Operations Manual*, Revision 2, March 1986.

Gene Galloway is a Senior Automation Engineer with Northern Telecom, Inc., and **Peter Goumas** is a Senior Applications Engineer with Lord Corporation, Industrial Automation Division.

Reader Feedback

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1	11	21
Excellent	Good	Fair

Vision-Based Robotics for Process Management

Laura L. Eliason and **James K. West**
Perceptron, Inc.
23855 Research Drive
Farmington Hills, MI 48024

A new measurement system that integrates advanced machine vision and robotic technology is providing manufacturers with a cost-effective solution for dimensional control. The system is a beneficial tool for stamping, fabrication, and assembly facilities when used to obtain measurements for the qualification and process management of large sheet metal or plastic parts and subassemblies.

In stamping plants, the flexible measurement system (FMS) is a plant floor tool for qualifying first parts following die changes and for monitoring regular samples as production proceeds. In the fabrication and assembly environments, the FMS offers a fast, ruggedized, and cost-effective means of measuring multiple styles and models of assemblies in a single station.

The key to this system lies in its relationship to other measuring methods, both traditional and modern. On one hand, the FMS is a flexible, automatic, and high-speed alternative to the manual part-checking fixtures prevalent in durable goods manufacturing facilities. A single FMS, surrounded by a set of simple holding fixtures, can replace an entire array of expensive, customized gauges, while simultaneously eliminating human error from the checking process. On the other hand, the system is a lower cost, higher speed, and completely automatic alternative to coordinate measuring machines. An FMS is constructed of rugged modules familiar to shop personnel. It can be placed right on the plant floor and does not require environmentally controlled surroundings. In addition, advanced sensing and software techniques called Visual Fixturing™ allow the FMS to find the spatial position and orientation of its workpiece prior to measuring, thus accommodating low-cost part presentation tooling.

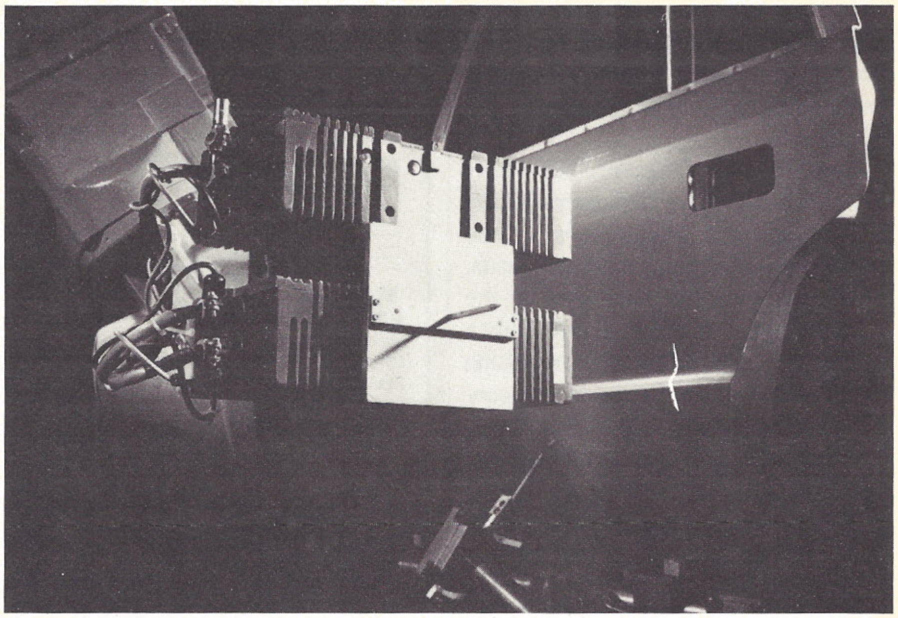

Photo 1. A beam of laser light is projected onto an automobile door subassembly by the laser within each sensor mounted on the robot's tooling plate.

SYSTEM COMPONENTS

As illustrated in Figure 1, the physical components of the FMS include the vision sensors and controller, the robot and its controller, and one or more part presentation fixtures into which workpieces are either automatically or manually loaded.

The vision sensors, rigidly mounted to the robot's end effector plate, can consist of a combination of one or more sensor types. The current family includes contour, surface, and feature sensors that are selected according to the type of measurements required (e.g., edges, character lines, surface orientations, and hole and slot positions). If the workpiece will be presented in an imprecise fashion, then a large field of view, low-resolution contour sensor is typically included in the set.

The vision controller incorporates the image processing, operator interface, data management, and robot communication functions. By means of proprietary algorithms, the controller derives real dimensional measurements from images acquired by the sensors. The operator interface uses a color CRT and a light pen to facilitate the setup of measurement types and sequences, the calibration of the system, the display of measurement status, and access to a comprehensive statistical process control reporting package. The data management subsystem provides an archive for many thousands of part measurements as well as a floppy disk backup

module. Robot communication is via both serial I/O for transmitting visual fixturing matrices, and parallel I/O for vision/robot and line controller synchronization.

The FMS architecture supports the use of either an articulated or a gantry robot. It is essential, though, that the robot is one of a relatively new generation of machines that possess a high level of both static repeatability and relative accuracy. It is important to note that since the measurement path is derived from a pre-taught path, the robot's absolute accuracy is not a critical performance issue. The robot's controller must be able to accept a six-dimensional offset matrix (x,y,z, and roll, pitch, yaw) over a serial communications link. This matrix allows a capable controller to spatially shift a pre-taught path, based on visual input, so that the subsequent path coincides with the new observed workpiece position.

SYSTEM FUNCTIONALITY

Managing an automotive door assembly process is challenging because of the many complex surfaces involved. Character and belt lines of the door must eventually line up with similar features that sweep across the car body. In addition, the door header must seal properly to avoid wind noise and water leaks. The process of attaching the door hinges establishes, in all three dimensions, the final relationship between the door and the car. It is therefore necessary to closely monitor the hinge attachment process to prevent process drift, which will initially produce poor door fits and eventually produce scrap.

An FMS is being used today, measuring hinge-to-door coordination and providing process management feedback to assist a manufacturer in producing a quality product. The system's sensor set, mounted on the tooling plate of a Cincinnati Milacron T3-776 robot, includes a 50-mm field of view, a low-resolution contour sensor for visual fixturing purposes, and a 20-mm field of view, high-resolution contour sensor for door qualification. When activated by the vision controller, the laser within each sensor projects a planar beam of light onto the part surface. This light, as it is reflected from the part, is viewed by the sensor's camera using an optical triangulation technique. The captured image is processed and compared to defined specifications. The robot controller is equipped with a three-dimensional frame alignment subsystem, improved computational resolution software, and a floating point coprocessor to maximize its relative accuracy.

To illustrate the FMS's functionality, let's summarize the operational sequence required to perform the hinge coordination task:

1. After the spot and fusion welding processes that attach hinges to the door inner have been completed, any one of five models of door is shuttled automatically via a monorail conveyor into the FMS station. The door hangers are low-cost units capable only of repeatably positioning the doors to ±20 mm. As each door stops in the station, the line controller communicates the door model type to the vision controller, which then activates the robot and directs the selection of the proper pre-taught measurement path.
2. The robot first performs a preliminary visual fixturing by positioning the 50-mm low-resolution contour sensor at four datum points around the door

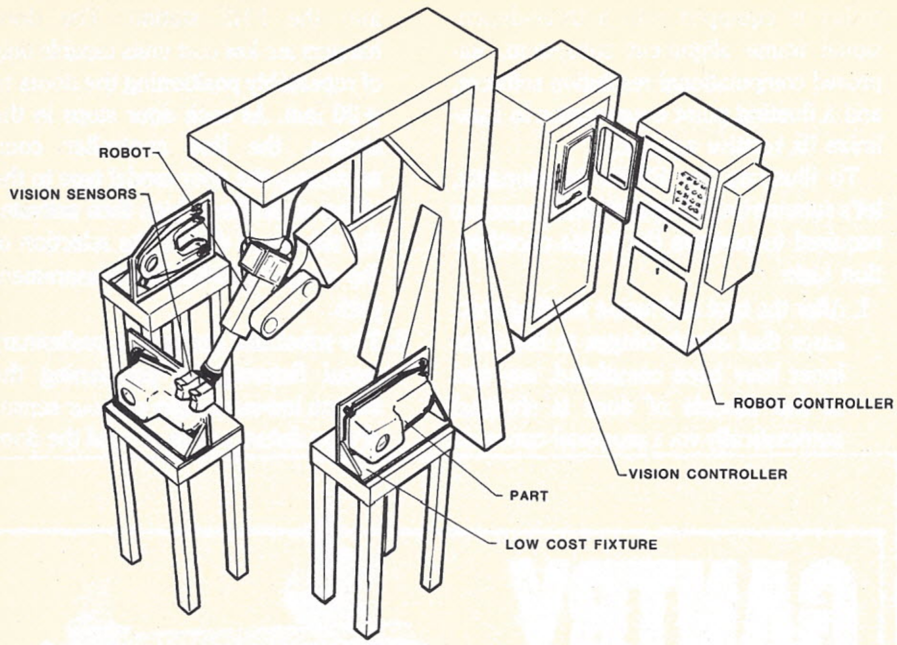

Figure 1. The principal components of a typical flexible measurement system include the vision sensors and controller, the robot and its controller, and one or more part presentation fixtures.

periphery. The measurements derived at these points reduce the uncertainty of door position from ± 20 mm to ± 0.5 mm in six degrees of freedom, and are used by the vision controller to compute an offset matrix that is transmitted to the robot controller over the serial link. The controller then uses this matrix to transform the subsequent inspection path so that it is physically shifted to coincide with the actual part position.

3. Using the shifted path, the robot proceeds to position the 20-mm high-resolution contour sensor to review each datum point. With these measurements, the uncertainty of part position is reduced from ± 0.5 mm to ± 0.15 mm, but the new visual fixturing offset matrix is retained within the vision controller to avoid the additional negative impact of the robot's relative inaccuracies.
4. The robot next uses the 20-mm sensor to measure the position of each of four hinge holes and performs seven additional user-defined measurements of door dimensionality. The accuracy of these individual measurements is $\pm$ 0.1 mm or better. After the measurement cycle is complete, the vision controller uses the offset matrix to compensate for any remaining mispositioning of the door.
5. If one or more hinge holes or user-defined measurement points are out of specification and/or trending out of specification, they are isolated and displayed on the color CRT for immediate notification and process modification. If all measurements are within specification, the system signals the line controller for part removal and readies itself to repeat the process on the next part.
6. All measurement data obtained during the cycle is output to system mass storage for future analysis and reporting on a demand basis. The reduced data is then used by manufacturing process engineers for tooling and/or process adjustments, as required, for management of the hinge attachment process.

The total process requires approximately 90 sec. of cycle time per door and provides an overall system accuracy of ± 0.25 mm, three standard deviations over the ± 20 mm part translation range.

SYSTEM BENEFITS

To fully understand the system's features and benefits in stamping, fabrication, or assembly, we need to compare the "old way" of off-line part qualification with the FMS approach.

Cost. Traditionally, expensive hard fixturing is required for highly accurate part measurement. The visual fixturing capability of the FMS eliminates this need. The cost of a single traditional hard tool part fixture can, in many cases, exceed the cost of the FMS itself. Only one part can be used per fixture, and if the part is changed that fixture becomes an expensive piece of scrap. Further, the labor costs incurred in the traditional, manual method can be up to $40,000 per year per worker. Such manual measurements are also slow, more likely to be inaccurate, and typically are not organized for action.

An FMS eliminates the cost of expensive fixtures by allowing the use of simple part carriers. The savings can be multiplied several times, as an FMS allows several different parts to be measured in the same station. Because the robot is adaptable, and the machine vision software can be taught new paths and measurement definitions, part qualification programs can easily be changed from year to year. In addition, the ruggedness of the FMS allows it to be placed on the plant floor close to the process being monitored, as opposed to the environmentally controlled environment required by the typical coordinate measuring machine.

Process Management. Manufacturers' processes must be properly managed to increase production quality while reducing costs. Statistical process control information that is accurate, timely, and reported in an organized fashion is absolutely essential. Manual data analysis methods are slow, inaccurate, and provide an inadequate sample size (usually two to four parts per day). The FMS offers a measurement approach that is flexible, fast, rugged, accurate, and that can provide a large sample size (about 30 per hour). The resulting data archive provides a valid sample from which to automatically generate statistical process control reports to aid in making process management decisions. In summation, the FMS represents a significant advance in dimensional measurement and control.

Laura L. Eliason is Marketing Communications Coordinator and James K. West is Vice President of Engineering for Perceptron, Inc.

Reader Feedback

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2	12	22
Excellent	Good	Fair

Cutting Composite Car Panels With a Waterjet

Robotics and waterjet technology are combining to speed automobile component production at the LOF Plastics plant in Fremont, Ohio. A number of formerly manual tasks are today performed by two Ingersoll-Rand/ASI robotic waterjet cutting systems (developed cooperatively by Ingersoll-Rand engineers, ASI robotic waterjet cutting systems, and LOF).

The waterjet system plays an important role in the Molded Products Group, a division of LOF Plastics that specializes in engineering and manufacturing components for a variety of industries, notably automotive. Here, several manufacturing methods are employed, including compression molding, injection molding, thermoplastic sheet molding, and profile extruding. We'll take a closer look at one method, the sheet molding method, and how the waterjet system fits in.

To produce Chevrolet Celebrity rear auto panels, parts of which are rated Class A surface (appearance grade), LOF Plastics first custom-formulates sheet molding compound (SMC), a high-strength, glass-reinforced thermoset polyester composite with a unique blend of mechanical, chemical, and electrical properties to fit the application.

Two layers of film are coated with continuous layers of polyester resin paste. The lower layer of paste receives random deposits of 1-in. lengths of fiber glass before the film is combined in a mat that passes through a chainbelt compactor that squeezes out trapped air. The processed sheet is wound onto a roll and placed in a temperature-controlled room to mature.

When ready to use, the roll is cut into blanks for the rear panels and placed in chrome-plated steel molds in a Williams-White 1500-ton press. After the 8½-lb. panels have been cooled and de-flashed, they are placed on a pair of piercing machines that knock out flat taillight and wiring holes from the front and back.

Bob Mollman, plant manager, comments, "These piercing machines are fine for punching out holes from a single surface, but the waterjet is well-suited for multiplane cutout," referring to the system's omnidirectional cutting ability independent of a starting hole.

After the initial cutouts are made, the panels are placed in a cage-like workcell with an optically controlled emergency shutdown (Photo 1) for secondary cutting by the waterjet. Ingersoll-Rand waterjets are manipulated by ASI five-axis robots with Allen-Bradley controllers programmed by LOF engineers.

The waterjet system is based on two processes—the intensification of water pressure via a pump, and the emission of the water through a specially designed sapphire nozzle. While the system has a design pressure of 60,000 psi, LOF Plastics operates its machine at about 45,000 psi, with water expelled at twice the speed of sound through an orifice of 0.008 in. Nozzle diameters range from 0.004 to 0.014 in., and it's this powerful concentrated force upon a very small area that produces the breakthrough cutting effect.

Cutting requires only six to eight gallons

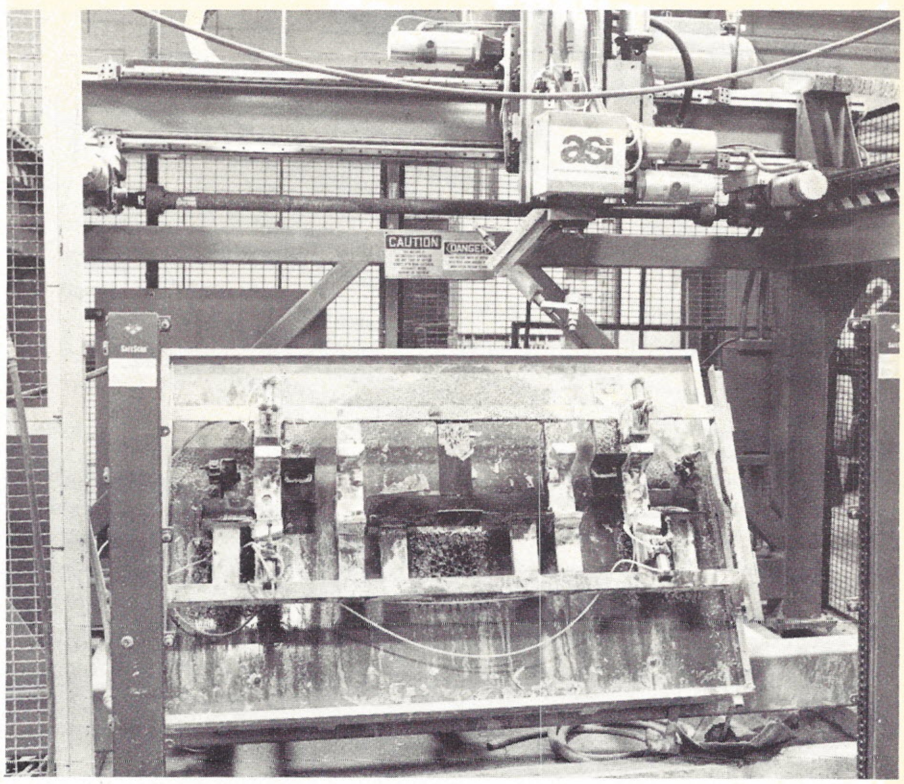

Photo 1. After the initial cutouts are made, panels are placed into the robotic waterjet cutting workcell for secondary cutting.

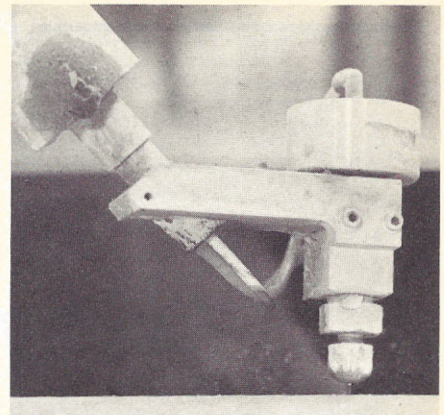

Photo 2. Water under intense pressure passes through the waterjet cutter's sapphire nozzle at twice the speed of sound.

of water per hour; waterjets can cut up to 300 in. of the 0.030 to 0.060-in. thick plastic per minute. No special filtering or draining operations are necessary. Following cutting, the panel surfaces are inspected for touchup by operators prior to painting.

In addition to consistency of performance, waterjets provide distortion-free cutting with no heat-affected zones, improved edge quality, instantaneous starting and stopping for added safety, elimination of retooling, and increased productivity.

On the latter point, Mollman notes, "The installation of the two waterjet systems last year freed the workers from the normal procedure and allowed them to perform a second job, drilling or driving studs in panels, while the water cutting was going on at another station.... While both waterjet and manual operations take about 55 seconds, we've become more efficient because previously we required two workers for the panel openings, drilling, and studding."

LOF Plastics, a Libbey-Owens-Ford company, has 35 plants and warehouses located throughout the U.S.

Ingersoll-Rand Waterjet Cutting Systems
635 W. 12th Street
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3	13	23
Excellent	Good	Fair

Sensor Applications in Robotics

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The superb mechanisms that support the body's data-gathering capability are nowhere more appreciated than in the field of robotics. Vision, hearing, smell, touch—all these and more are taken for granted by most persons not directly responsible for reproducing human senses in robots.

The first robots were designed for the repeated execution of preprogrammed sequences of motions needed to perform some dedicated task and were, for the most part, devoid of external sensing capabilities. Robots of the future, especially the mobile ones, will be required to operate in a constantly changing environment and be able to dynamically "sense" the outside world. For example, it has been estimated that the Factory of the Future will require as many as a million sensors to carry out its operations, many of which will be robot driven. Recognizing the importance of robotics in future space programs, NASA has placed robot sensing on its list of highest priorities for future development.

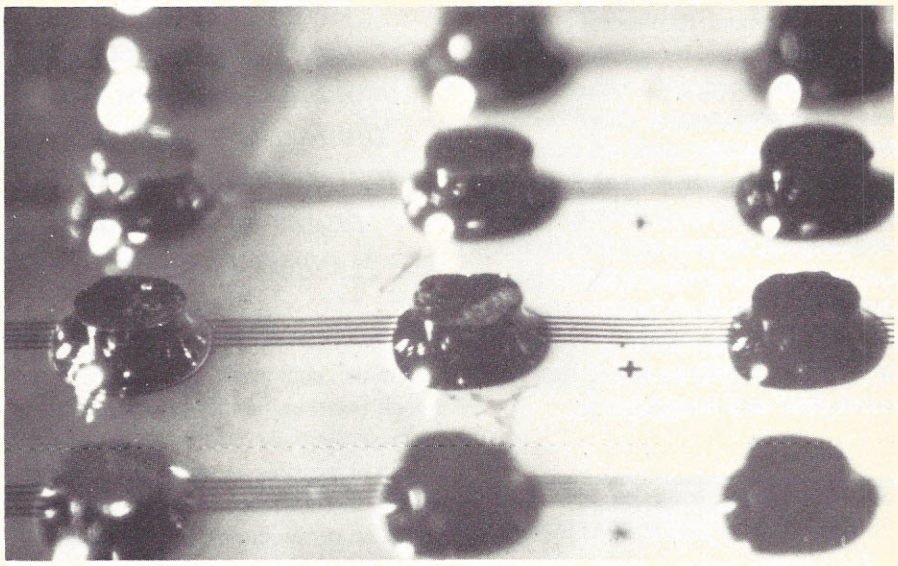

Photo 1. In a flexible sensor array, silicon islands with connecting wires are embedded in a flexible polyimide substrate. Horizontal separation between islands is 1.5 mm.

Sensors in robots can be categorized as *internal* and *external*. Easiest to implement, internal sensors measure the inner variables that are important to both robotic control and system well-being. For example, the control of a manipulator is highly dependent on knowing the position and velocity of every joint at all times. Such "proprioception" involves the strategic placement of position sensors to measure each joint angle and extension. Today, such **position sensors** are accurate enough to guide a six-joint arm anywhere within a 3-meter radius at an accuracy of 1 mm. Sensors that monitor robot well-being include those that measure **force**, **pressure**, and **temperature**.

External robot sensors provide an interface with the environment and include a number of devices, mechanisms, and technologies. **Vision systems**, perhaps the most developed technology, are used to give a robot its "eyes." Capable of analyzing a captured image of a scene and recognizing its contents, vision systems range from simple, one-dimensional binary optical detectors to complex computerized systems that can recognize three-dimensional objects based on gray-level shading of the image.

Another way to detect object presence is by using a **proximity sensor**. In the past, industrial robots have used simple devices such as inductive switches, limit microswitches, and photocell sensing. With the emergence of more sophisticated industrial

and space applications, especially those involving mobile robots, **range sensors** will become an important means of robotic determination of object location. Such devices will include **acoustic range sensors**, which have displayed millimeter accuracies over several meters, as well as **laser range finders** (well-developed by the military and surveying communities), which are accurate to within a millimeter over a distance of a kilometer (with the use of a retroreflector).

Scanning laser rangers have also been developed that can measure the reflectance of an object (to capture intensity images) as well as its distance. Unfortunately, the resolutions of both acoustic and laser rangers are too coarse to be useful in most manipulation applications.

To perform truly manipulative tasks, robots will have to be able to do more than sense a simple one-point contact with an object. Successful robot manipulation is dependent on being able to grasp an object and determine its physical characteristics—weight, size, temperature, thermal conductivity, hardness, surface texture, and spatial displacement. Called "taction," this complex sensing mode will have to use a **tactile sensor** that not only will detect how a two-dimensional surface is distributed in space, but precisely the amount of force required to grasp it without slippage during handling. Such tactile sensors can be expected to play a vital role in the ability of robots to identify an object, discern its orientation, and manipulate it.

TACTILE SENSING: THE GRASP WITH "FEELING"

Since tactile sensor systems, along with vision systems, will be the primary means by which a future robot will perform its work, more attention is being given to these two than ever before. While vision is essential for identifying objects and avoiding obstacles, it is the tactile sensor that will determine whether proper grasp of an object has been achieved—e.g., just enough force to manipulate a delicate object like an egg without breaking it, or to firmly grasp a hammer without dropping it.

Defined by the late Leon D. Harmon of Case Western Reserve University, a pioneer in the field, as "continuously variable touch sensing over an area within which there is spatial resolution," tactile sensing differs from **force** or **torque sensing**, which is restricted to a single point. Although sensing over a two-dimensional space can be achieved by passing one or more individual sensors over the surface to be examined, data capture is made quicker by constructing tactile sensors as arrays of individual sensing elements, with resolution determined by how closely array elements are packed. While the difficulty of processing data from parallel arrays increases with the size of the array, parallel processing affords the best means of obtaining real-time imaging from tactile sensors, an important consideration when robots are required to react quickly to changing events.

In many ways, the surface discrimination required for taction is similar to that of computer vision. Both must continuously sample signals derived from an object's area or volume, which must then be translated into a recognized pattern through real-time computer techniques. Since much research has already gone into vision sensing over the past 25 years, it might be possible to adapt a large portion of the methodology to tactile sensing.

While vision is essential for identifying objects and avoiding obstacles, it is the tactile sensor that will determine whether proper grasp of an object has been achieved.

To be successful on a general-purpose robot manipulator, tactile sensors should be designed to be functionally equivalent to sensors on the human fingertip. As such, they will require:

- Many sensor elements, typically from 64 (8×8) to 256 (16×16), to minimize tactile imaging time
- Close spacing of array elements for fine spatial resolution, approximately 1 mm center-to-center
- Ability to conform to a convex "fingertip" surface for taction with curved surfaces
- Ability to sense both force and temperature to simulate biological touch
- Sensitivity to a wide range of forces, typically from 1 to 1000 grams per element
- Tolerance to over-scale forces without damaging the sensor
- Fast response time (wide bandwidth) for optimum data sampling rates, typically 100 Hz
- Low output hysteresis (constant response to changing forces)
- A robust "skin" that will survive environmental extremes
- "Graceful" failure during performance (survival of the remaining portion of the array when some elements are damaged)

Additional desirable characteristics are:

- The ability to sense shear (off-normal) forces to detect slippage of a grasped object
- A local pattern processing capability (to reduce the transmission bandwidth to the robot data processor)
- A cost-effective sensor fabrication technology
- Additional nonbiological functions (capacitive proximity sensing, for example) for more capability

Although the amount of literature reporting on tactile sensor progress has increased considerably over the past few years, no tactile sensor array has as yet come even close to meeting the preceding specifications. It is important to keep in mind, however, that most research is still in the experimental stages. In general, most tactile sensors that have been developed fall into four categories: optical sensors, piezoresistive sensors, piezoelectric sensors, and capacitive sensors.

In an **optical sensor**, a light source is modulated in direct correlation with a force deflecting a flexible sensor element. Although most research dealing with this technique is still experimental, commercial products for the assembly line have been introduced, applicable primarily to flat, tactile work surfaces for part recognition, location, and orientation. When applied to robotics, though, the relatively large size of some emitter/detector designs might limit the resolution of a tactile array. Nevertheless, research on fiber-optic transmission techniques promises to bring such resolutions down to less than 1 mm.

Piezoresistive sensors are primarily of two types: silicon strain gauges and conductive elastomers. Both rely on the changes in electrical conductivity of the active material as it is stressed by force or pressure. Silicon sensors have seen their primary commercial use in recent years in

the auto industry, where on the order of 15 million pressure sensors are used annually in harsh "under-the-hood" environments, and in the medical industry, where they form the basis of some five million disposable pressure sensors. If designed properly, silicon sensors (which are based on the same fabrication techniques used in IC technology) could form the basis of tactile arrays that conform to many of the needs in a robotic system, including high resolution and sensitivity, multifunction capability (temperature and other sensors), low hysteresis, fast response, local processing (ICs can be fabricated directly onto the chip alongside the sensor), survivability, and low cost. At least one silicon tactile sensor is now commercially available in a 3×3 flat-pack array (2 mm resolution). One researcher has reported development of a polysilicon tactile sensor that can measure shear forces as well as forces normal to the surface of the sensor.

Because of their greater conformability to irregular surfaces, as well as their low cost, conductive elastomers have received much attention from tactile sensor researchers. Unfortunately, they suffer from low sensitivity, high hysteresis, long time constants, and fatigue—and they are noisy.

Based on the generation of an electrical charge in response to an applied force, **piezoelectric sensors** are the only sensors that do not require an external voltage to operate. Although quartz and ceramic are classic examples of materials that exhibit the piezoelectric effect, most research has concentrated on piezoelectric polymers, which are low in cost, conform to irregular surfaces, exhibit high durability, and display good resolutions. (These versatile sensors are also capable of displaying pyroelectric phenomena, a capability that could form the basis of a temperature sensor.) Unfortunately, a decided disadvantage of piezoelectric sensors is the fact that they will operate only while the active material is being deformed.

Capacitive sensors are designed on the principle of two metal plates' acting as elements of a capacitor. As the distance between the plates changes, in response to some force or pressure, for example, so does the capacitance, thus altering the electrical characteristics of the circuit. Such sensors, made of silicon, have long been used to measure pressure in the auto industry, but have only recently seen use in experimental tactile sensors. Some capacitive sensors have the advantage of extreme sensitivity (in the microns of Hg range) to changing pressures.

SOME RECENT BREAKTHROUGHS IN TACTILE SENSING

Two efforts at Stanford University illustrate some of the current directions in tactile sensing. One group is developing a monolithically fabricated, flexible array of force and temperature sensors, while a second is obtaining data with a capacitive force sensor array.

The first group (Mark Zdeblick, Patricia Beck, and Zenon Kuc of the Electrical Engineering Department, along with this writer as consultant) is fabricating experimental 5×5 arrays of piezoresistive silicon force/temperature transducers. Based on a technology for making flexible arrays that was previously developed at Stanford's Center for Integrated Systems, these arrays consist of silicon islands and connecting wires embedded in a flat, flexible polyimide sheet, which can be molded into a fleshy polymer "fingertip" beneath a protective polymer "skin" (Photo 1).

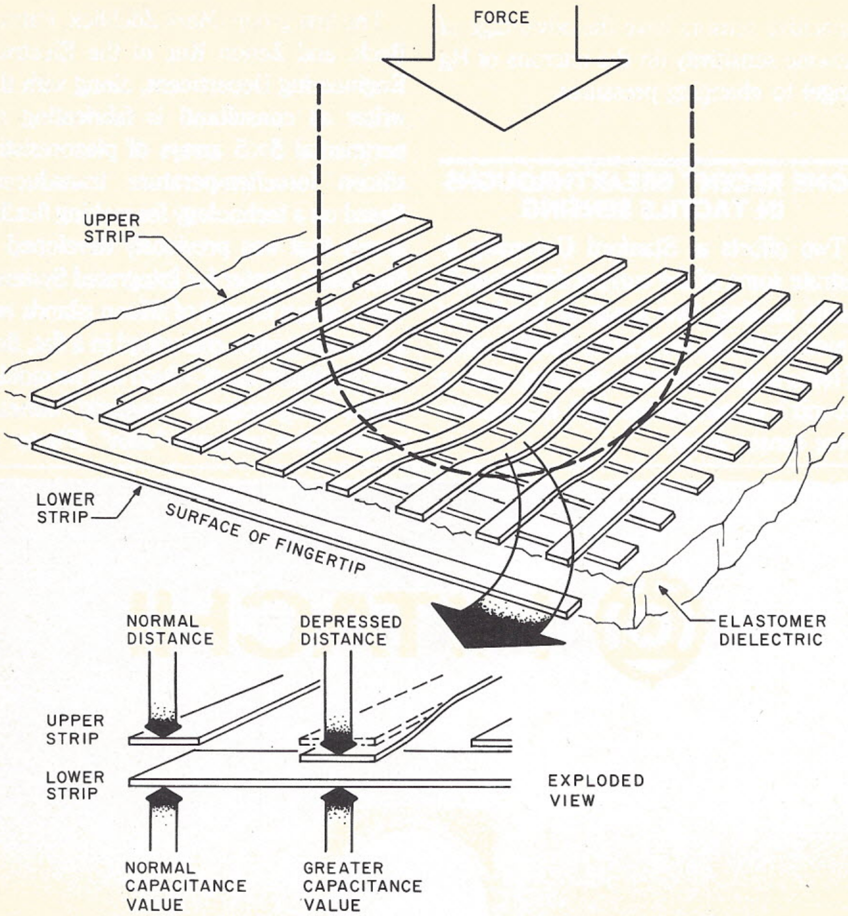

Figure 1. A capacitive tactile sensor array is based on capacitive force sensors buried in a polyurethane foam "flesh" cast around a steel "bone" in a 1-in. diameter fingertip.

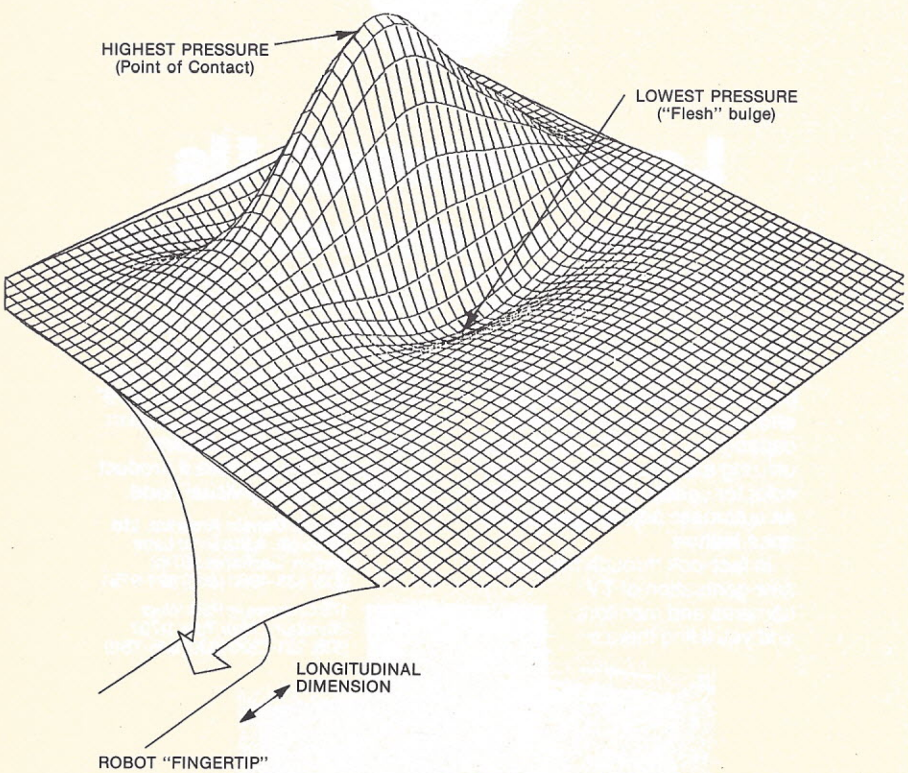

Figure 2. A point load on the tactile sensor in Figure 1 shows that a point load applied on one side of the fingertip causes a response over a large area of the fingertip, and that the local pressure actually decreases in some areas of the fingertip, corresponding to a stretch response in addition to a pure compression response.

Each silicon island contains four force sensors, so that a force applied at some angle away from the perpendicular, causing the island to "rock" away from its undisturbed orientation, can be detected as a differential signal over the four sensors. This sensing method is intended to give data on "shear" forces as well as perpendicularly applied "normal" forces, thus detecting friction and slip in addition to grasp force.

Stanford's second group (Ron Fearing and Professor Tom Binford of the Artificial Intelligence Laboratory) has already obtained results of force distributions within a fleshy robot fingertip. The researchers used capacitive force sensors buried in a polyurethane foam "flesh" cast around a steel "bone" in a fingertip about 1 in. in diameter. The capacitive sensors are fabricated using crossed copper strips separated by an elastomer dielectric; capacitance of each strip crossing can be monitored sequentially using external electronics (Figure 1). Data obtained from this sensor (Figure 2) shows that a point load applied on one side of the round fingertip causes a response over a large area of the fingertip, and that the local pressure actually decreases in some areas of the fingertip, corresponding to a stretch response in addition to a pure compression response. The axis from lower left to upper right corresponds to the length dimension of the fingertip, while the axis from upper left to lower right corresponds to the circumferential direction around the fingertip. Increased pressure (the highest peak) where the load is applied is accompanied by decreased pressure (troughs) as the "flesh" bulges away from the contact point. The mesh shown in Figure 2, much finer than the 8×8 array can produce directly, is produced by interpolation using a model based on the characteristics of the fingertip material and geometry.

Phillip Barth, who holds a Ph.D. in electrical engineering, is Program Director for Special Sensor Development at NovaSensor.

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4	14	24
Excellent	Good	Fair

Machine Vision for Electronics Manufacturing

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Machine vision plays an integral role in many of today's manufacturing processes. In every major industry, vision systems can be found performing inspections, locating parts for assembly and sorting operations, and guiding robot movement. The benefits of machine vision are clear: when added to existing machinery, it provides closed-loop feedback; when incorporated in new machinery, it offers unprecedented accuracy; and when established in standalone inspection stations, it monitors high-speed machines to ensure quality production.

Machine vision technology has been particularly successful in the electronics industry, where the demand for printed circuit boards and components is increasing steadily. To meet this demand, manufacturers are adopting new technologies, including those that use surface mount devices (SMDs). Other manufacturers are refining their old processes to make them faster and more cost-effective. This includes automating the assembly of through-hole components with nonstandard packaging.

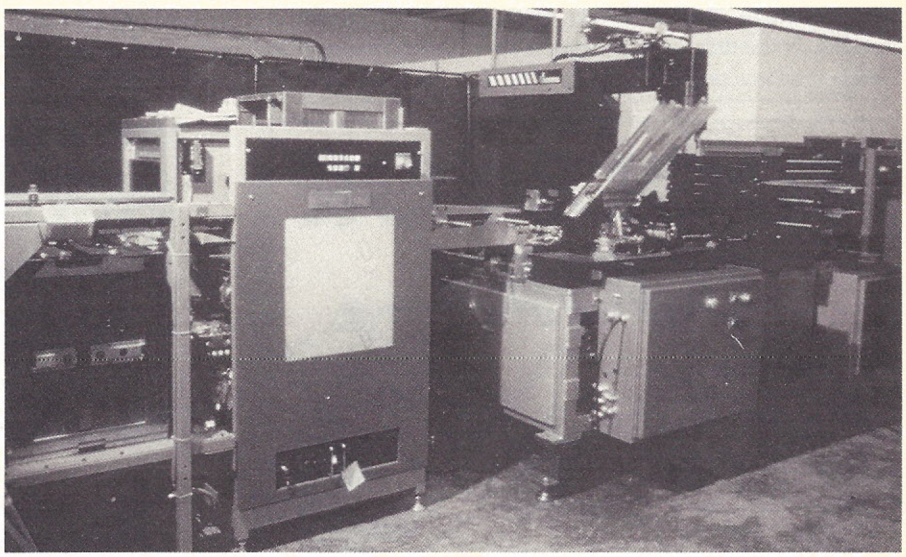

Photo 1. The automatic PCB assembly at Rockwell Wescom includes a six-axis Cartesian robot with a servoed gripper and interchangeable fingers.

STANDALONE INSPECTION OF SMDs

The introduction of surface mount technology has created new inspection problems traditional methods cannot solve. The components are much smaller in size (often as small as 0.050 in. × 0.100 in.), and more densely placed (a large computer board might have 200 or more components). It is also difficult to tell whether components are properly located, since SMDs do not have leads protruding through the board.

Most SMDs are placed by high-speed assembly systems at rates of 10,000 to 12,000 components per hour; some specialized machinery claims rates as high as 184,000 placements per hour. To inspect these quantities and prevent backup at in-circuit test equipment, or a large queue of improperly assembled boards, a high-speed inspection operation must immediately follow the placement process. If the inspection takes place before solder reflow, faulty boards can be easily reworked, and high reliability and throughput can be achieved.

The actual configuration of a standalone

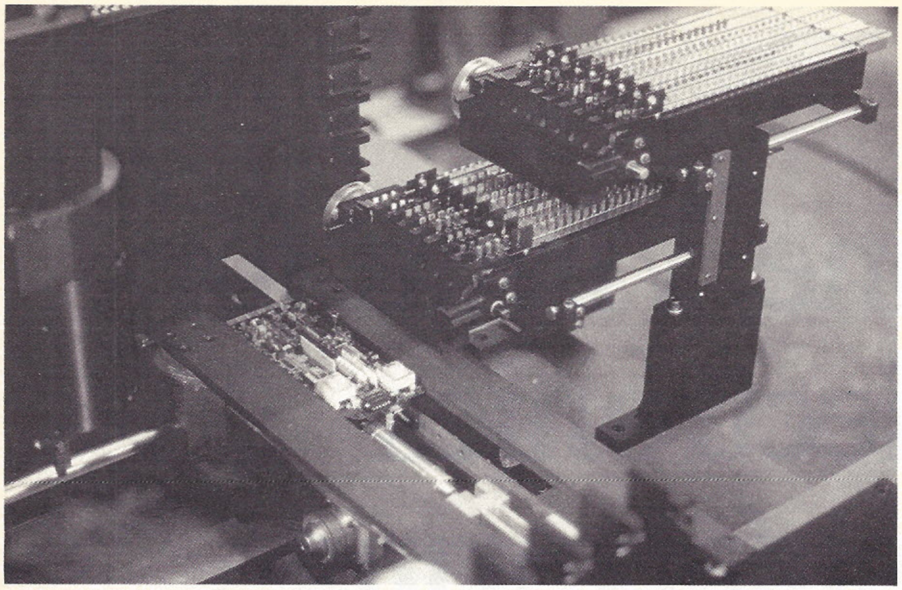

Photo 2. Two component presenters are shown: flexible (left) and radial.

inspection system varies, depending on the application's requirements, but the system will usually include one or more cameras, board transport hardware, a vision processor, and appropriate lighting and optics. Generally, there are two types of systems. In the first, a component is completely seen in a single field of view (FOV). The camera is mounted to an x,y table, and the FOV moves from component to component. Such a system is easily reprogrammed and can accommodate a wide range of board sizes. High reliability is provided by matching the lighting to the particular lens being used. The second type of inspection system uses multiple FOVs to inspect a single component. This array of cameras is useful for high-speed inspection of single-board configurations, and the system's increased throughput justifies the more complex approach. Typically, vision suppliers offer one type of system or the other, although some of the more advanced companies offer both.

VISUAL VERIFICATION DURING SMD ASSEMBLY

An alternative to standalone inspection is vision integrated assembly, in which inspection takes place after assembly but before solder reflow. By incorporating vision into the assembly process, the inherent problems encountered in handling and placing surface mounted components are eliminated. Most of the SMDs assembled with the high-speed placement machines are discrete—they have no more than three terminations. The other type of surface mount component is referred to as an active device, and it can have well over 200 terminations, imposing tight assembly tolerances. Whereas a typical discrete component can be assembled within a tolerance of 0.010 in. and an

angular tolerance of 5 to 6 degrees, an active component having 172 leads on 0.025 mil centers must be placed within a tolerance of 0.003 in. and have an angular misorientation of no more than 0.1 degree.

Further complicating the tight assembly tolerance problem is the lack of precision between the board artwork and the component lead frame. The artwork is photoetched to the substrate in a separate operation from that in which the mechanical features of the board are created. Because these processes are separate, there is an insufficient relation between the artwork and the mechanical features of the board. In addition, the component lead frames suffer from distortion and a poor relationship between molded body and lead frame.

When determining whether a placement system can accurately place components with acceptable reliability, the system's maximum error must be calculated. For SMD placement, there are three fundamental error sources: machine, board, and component. Table 1 lists the error sources and tolerance stackup for both the through-hole and the SMD assembly processes. For each error source, two factors are listed—an x,y translational error and a rotational error. The x,y translational error gives a measure of how far the center of a lead will be displaced from the center of its pad as a result of a particular error. The rotational error gives a measure of how much a component will be rotated relative to the pads. But, as shown in the table, an assembly system using machine vision can meet these stringent placement requirements.

Table 1
Comparison of Manufacturing Tolerances

	Through-Hole		SMD Without Vision		SMD With Vision	
	Translation (in.)	Rotation (mrad)	Translation (in.)	Rotation (mrad)	Translation (in.)	Rotation (mrad)
Machine						
Repeatability	0.001	NA	0.001	NA	0.001	NA
Accuracy	0.005	NA	0.005	NA	NA	NA
Fixturing	0.002	0.1–0.5	0.002	0.1–0.5	NA	NA
Tooling	0.001	1.0	0.001	1.0	NA	NA
Board						
Mech. features	0.002	0.1–0.5	0.002	0.1–0.55	NA	NA
Artwork	NA	NA	0.001	—	0.001	NA
Artwork to mech. features	NA	0.2–0.6	0.006	0.2–0.6	NA	NA
Distortion	0.002	NA	0.002	NA	0.002	NA
Component						
Lead distortion	0.004	1–2	0.001–0.004	0.5-2.0	NA	NA

17 mrad (milliradians) = 1 degree
1-mrad error at 1-in. radius = 0.001 in.

MACHINE VISION CLOSES THE LOOP

To make automatic placement of 0.05 in. and 0.025 in. devices feasible, users in-

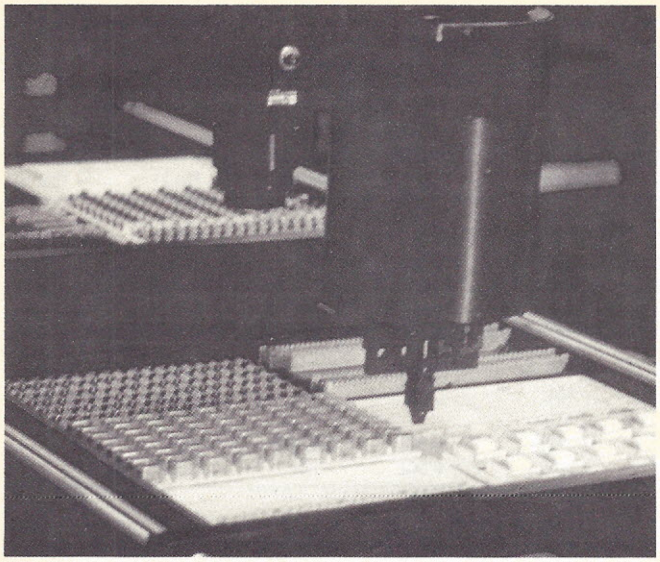

Photo 3. These are examples of the variety of components stored in the flexible component presenter.

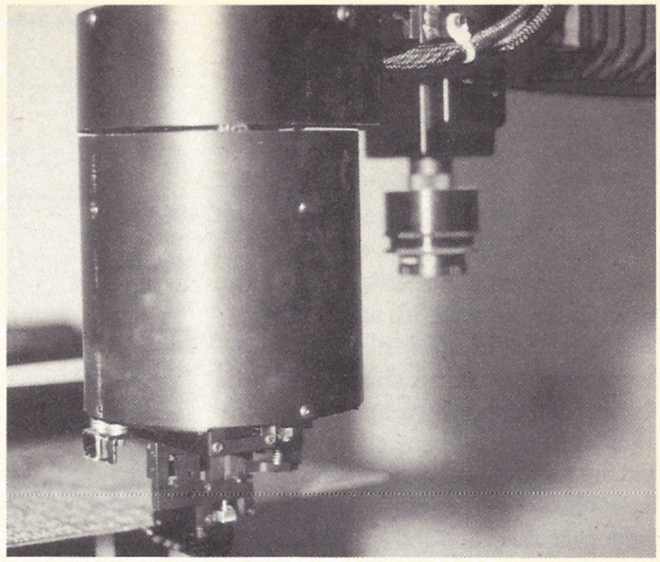

Photo 4. A camera mounted on the robot's arm provides vision for board artwork registration.

corporate sensing systems into the placement machine to correct for board and component misalignment. Machine vision is favored for surface mount assembly because it is flexible and easily reprogrammed. Vision has also been applied to through-hole assembly, but for different reasons. In the case of through-hole, it is not the accuracy that needs enhancement, but the flexibility of the machine to adapt to different component types. This is important when dealing with non-standard or odd-formed components, those devices for which a generally accepted packaging standard has not yet been developed. It is difficult to develop automated machinery to handle these components, and today's "blind" machines have been able to handle only one or two of the component types.

An alternative strategy is to introduce vision to the system to identify the lead locations, as in SMD assembly, and to use this information to offset the nominal insertion location. This approach obviates dedicated tooling for lead alignment prior to insertion, except where lead forming prior to insertion is required. An assembly system can thus be readily adapted to a variety of different assemblies by merely updating the database.

MACHINE VISION'S FLEXIBILITY

The above represent only a subset of the total applications in electronics for machine vision technology. The ability to closely monitor both inspection and assembly processes, while at the same time providing statistical process control, ensures that quality printed circuit boards and products are built in a cost-effective manner. Flexibility, crucial in today's volatile markets, is provided by database-driven systems with adaptive vision.

Automatix uses vision in two ways to compensate for mechanical errors. First, for boardwork registration the camera establishes the artwork's reference frame by observing fiducials on the board. Fiducials are prominent, recognizable features included in the artwork to simplify visual registration. They can be as simple as circles etched on the board in known locations. The system needs at least two fiducials to establish the artwork reference frame. Additional fiducials allow the system to use mathematical modeling techniques to compensate for board distortion. Fiducials local to a given pad set provide the highest degree of accuracy and are recommended for those components where the misalignment tolerance is small.

By using vision to compensate for errors in board and pad location, a system can guarantee that the placement arm moves to the proper board location, but once the arm gets to the proper location, component lead distortion and centering errors within the placement jaws can still lead to

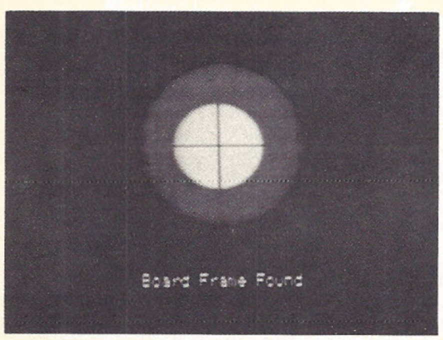

Photo 5. The CRT identifies a tooling hole fiducial.

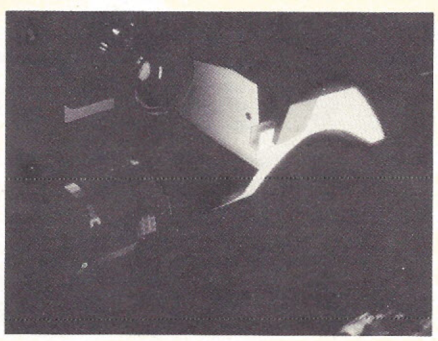

Photo 6. Component leads are inspected by the two-camera vision verification station.

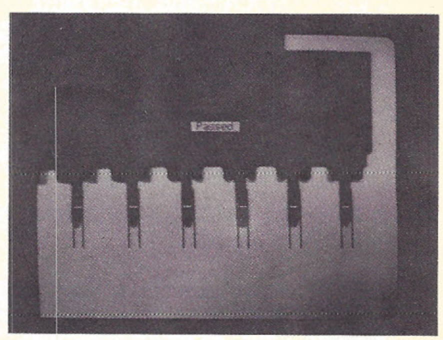

Photo 7. An image of the component under inspection appears on the CRT.

an unreliable placement. To compensate for lead and centering errors, Automatix uses a separate camera to photograph the component while it is on the vacuum chuck. With this information, the placement arm can be guided to correctly align the component's leads with respect to the pad locations. If the leads are out of tolerance, the part will be rejected, resulting in a higher product yield than is possible without machine vision.

Briefly put, machine vision provides a cost-effective way of reliably placing surface mounted devices. Expensive, precisely made boards and components are not required. Process reliability is improved by component inspection and placement verification so that higher process yields can be expected.

Jeff Bodenstab is Electronics Product Line Manager at Automatix Inc.

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5	15	25
Excellent	Good	Fair

A Case Study

At the Wescom telephone communications division of Rockwell International in Downers Grove, Illinois, two Automatix assembly systems build complex and expensive PCBs as part of the manufacture of telephone switchgear equipment. The completely automated system's hardware includes a six-axis Cartesian robot with a servoed gripper and interchangeable fingers; an AI 32v robot vision controller; and a 10 × 10 ft workcell, complete with a variety of component presenters, a cut-and-clinch mechanism, and stacker buffers to store and transport boards during the assembly process.

The system is designed to handle non-standard component assembly, and relies upon in-process verification for quality control. The system incorporates both vision and force monitoring to reduce errors, as well as to report the type and location of assembly problems. This system offers the kind of flexibility desired by manufacturers who need to change boards, parts, or both.

The Wescom boards are populated with a variety of odd-formed components such as SIPs, hybrids, switches, DIPs, axials, and radials, each with a different lead size, lead length, lead dimension, and body shape, making the presentation and handling of these parts tough and time consuming. The kinds of errors occurring from manual assembly are improper orientation, missing components, and wrong components. Using an arm mounted camera, the system incorporates vision for registering board position, which negates the need for hard tooling to locate the board. Because the system is data-driven, changing the board type and building new boards is a simple matter of putting a new disk with data into the AI 32v. No reprogramming is necessary. All that is required is to fill in the data structure and insert the correct components.

The system uses vision also to find the part length and location in space, and offsets the component against the board tooling holes located earlier. Component insertion is based on the correct board angle. While held in the two-camera lead verification station, lead and orientation information is provided to the robot, allowing for accurate insertion. Force sensing in the servoed gripper verifies that insertion took place.

At the heart of the assembly workstation is the AI 32v, incorporating robot control and machine vision in a single factory-hardened cabinet. It is the workstation host, controlling the robot mechanism, managing cell peripherals, collecting and assessing production information, and communicating with other factory data and control systems. The core assembly program provided by Automatix, and standard for all boards, can be coupled to databases that allow the customer to tailor the system to specific board and component requirements. They include: PCB database, component database, workstation database, and shop floor database.

Rockwell Wescom is typical of electronics manufacturers who are seeking to automate their assembly processes and provide better quality control over product, while gaining statistical process control feedback. More and more PCB assembly users are turning to vision to build correct boards before final inspection takes place, reducing and eliminating costly rework.

With the vision, flexible component presenters, and flexible tool-changing features of the PCB assembly cell, part assembly on the Wescom board is handled with greater speed and accuracy, resulting in better built boards.

Edited by Stephanie vL Henkel

GMF RETRENCHES

In a move certain to have a profound impact on the robotics industry, GMF Robotics has announced a corporate restructuring, curtailment of plans for the firm's new headquarters, reduced earning forecasts for the year, increased fiscal conservatism—and the layoff of 200 of a 690 workforce by the end of the year.

The announcements were made at a news conference called by Eric Mittelstadt, GMF president and CEO, on August 8. He delivered the news to a meeting of the entire company earlier that day, receiving applause from the employees both before and after his address.

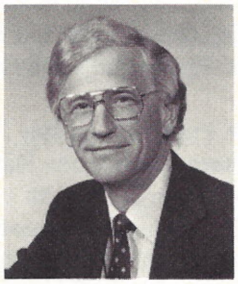
Various spokesmen for GMF, the largest robotics company in the world and a joint venture between General Motors and the Japanese robotics firm Fanuc, stood firm in asserting that the recently disclosed joint venture between General Electric and Fanuc had absolutely no bearing on GMF's cutbacks. The root of the problem, they said, was a general slump in the automotive industry. GM has recently cancelled or delayed a number of large contracts, including several with GMF, which had been hiring in anticipation of fulfilling those agreements.

Mittelstadt put a dollar figure of $88 million on order cancellations for 1986 and 1987. GM cutbacks, not all of them necessarily in robotics, represented 80 to 90 percent of that amount, he said. While GMF does sell to firms other than its parent company, GM nonetheless accounts for 75 percent of GMF's business. Some of the slack was taken up by "excellent growth in our non-automotive markets," Mittelstadt said, but went on to predict that business would "flatten out" for two or three years.

Sales in 1985 were $187 million. The first 1986 estimates were for "well over $220 million"; that figure has been reset at $190 million. Last year's profit was $10 million; the company will "do well to break even this year," Mittelstadt said. He announced four major goals: "increased sales, improved execution of orders, reduced costs, and maximum motivation of our people." GMF has already begun a comprehensive program to strengthen its financial performance, including efforts to conserve working capital, reduce expenses, and improve profitability. After the corporate restructuring, Lothar Rossol, vice president and chief technical officer, will be responsible for all product development operations. Sales and service resources will be concentrated into three customer groups.

 Circle 53 Circle 47

Mittelstadt Comments



In a telephone interview subsequent to his press conference, Eric Mittelstadt, GMF president and CEO, described the GMF layoffs as "a sad and difficult decision." GMF had arranged a plenary meeting of its personnel directly before going public with the news. "We wanted to tell our people first, and then the press," he said. Rumors of impending layoffs were already in the wind, and as of August 12, GMF had been advised of 200 job openings, the great majority of them in the Troy area. "That's going to make us feel better," Mittelstadt said. The firm is also actively conducting a job placement program for those among the departing 200 who do not plan to retire.

GMF's troubles did not come out of the blue. "We had a meeting three months ago, when I said we had some serious problems coming and it was going to be one tough time," Mittelstadt said. "Some of the things we had counted on materializing have not been finalized. It could be several years before the programs GM had talked about would happen. It became clear that business wasn't going to come back the way we thought it would." A salary reduction approach was considered and rejected, he said, because it might have taken two to three years before current salaries could be reinstated. Asking his employees to accept such a wait would have been "unfair," he said, and too, problems could arise from other companies' throwing dollars at GMF's engineers in an effort to lure them away.

While GMF has for some time been working to diversify its product market, the present crunch came partly from the company's not being nimble enough to make up in three months from its other markets the $88 million it was expecting from GM and other contractors. But the firm intends to take aggressive measures to prevent a recurrence. "Our focus is to accelerate the broadening of our customer base," Mittelstadt said. "Nothing is going to dominate the robotics industry the way the automotive industry has—and we're going to make sure of that." Last April GMF announced its entrance into the AGV business via a joint venture with Eaton-Kenway. The firm also has its eye on electronics assembly and the food and beverage industries, among others.

Mittelstadt's optimism appears unshakable. The newly slimmed down version of GMF will still be the robotics industry giant, he said. Its competitors are more than likely "rubbing their hands in glee that we have a problem. I bet they wish they *had our problem. We will definitely survive, and come out of this stronger than before."*

CORPORATE NEWS

► **American Cimflex** has received a $1.2 million order from **Ford** for a flexible, robotic dispensing workcell to be

In The Robotics Age™

installed at Ford's Lorain, Ohio plant. The workcell will feature two gantry Merlin robots applying adhesive to the roof headers of Thunderbirds and Cougars.

► **Prab** will supply **Mazda Motor Corp.**'s new Flat Rock, Michigan facility with a $1 million just-in-time automatic truck unloading system. Prab will be responsible for the engineering, manufacture, and installation of the system.

► **IMEC Corp.** has been acquired by **Pacific Scientific.** IMEC's founders came out of Draper Labs, and the company, founded in 1980, has specialized in the development of electronic controllers that link computers with servo motors in robots and other forms of factory automation. The founding engineers will remain with the company.

► **GM Canada** has awarded **Litton**'s Industrial Automation Systems group a $10.7 million contract to provide an overhead monorail delivery system for its Oshawa, Ontario body and assembly plant. The 10,000 ft. long system, outfitted with 340 automobile carriers, will transport 66 partially assembled auto bodies per hour through the production line.

► **UAS Automation** has received a $500,000 order from the New Departure Hyatt Bearing Division of **GM** for a multi-robot material handling system that serves a dedicated assembly machine. The system will be part of the GM-10 manufacturing program.

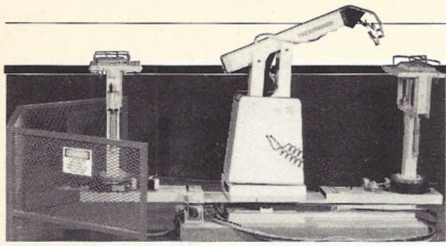
CALL FOR PAPERS

The **ASME Design Automation Committee** has issued a call for papers for presentation at the 1987 Design Automation Conference to be held September 27–30 in Boston, Massachusetts. The deadline for manuscripts is March 1, 1987. Five copies of each paper should be sent to Professor S.S. Rao, School of Mechanical Engineering, Purdue University, W. Lafayette, IN 47907, telephone (317) 494-5699.

ORGANIZATIONS

► **ASME** and the **National Fluid Power Association** have agreed in principle to enter into a joint venture to advance fluid power technology in the U.S. through sponsored R&D, greater involvement in education, and publication of a technical bulletin. The Fluid Power Research Institute will supplement and be fully coordinated with the NFPA, National Conference on Fluid Power, Fluid Power Educational Foundation, and other allied organizations. The institute's first project will be a report on R&D projects in hydraulic and pneumatic technology completed or under way in research institutions and corporations around the world.

New Products



Spray Painting Robot Comes Complete

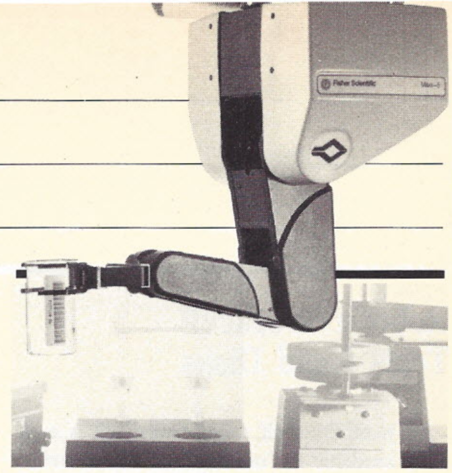
The PartPainter automation cell for mask spraying and small part painting consists of an industrial spray painting robot mounted on a rotating part positioner. The positioner has two stations, one in front of the robot and one to the rear where it can be loaded and unloaded. After the robot sprays a part, the positioner rotates the painted part for unloading and rotates a new part in front of the robot for painting. The robot's base swivels under its column. The positioner can also rotate the part in front of the robot to facilitate the painting process. The system comes with all electrical, hydraulic, pneumatic, and control valves; lines; fittings; and switches.

For more information, contact: Thermwood Corp., Robotics Div., PO Box 436, Dale, IN 47523, telephone (812) 937-4476.
Circle 100

Casting Robot Has Two-Ton Payload

The Model 1360 six-axis robot is designed to handle large molds and castings for the investment casting industry. It is also suited to operations that require dipping, sand slurries, and other repeatable production procedures. Features include a payload of up to 4000 lb.; 360-degree continuous boom rotation; and special tooling with a 360 rotator, 270-degree roll, and clamp functions.

For more information, contact: Mike Collins, Action Machinery Co., PO Box 10125, Portland, OR 97210, telephone (503) 228-2987.
Circle 101



Lab Robot Can Be Mounted Overhead

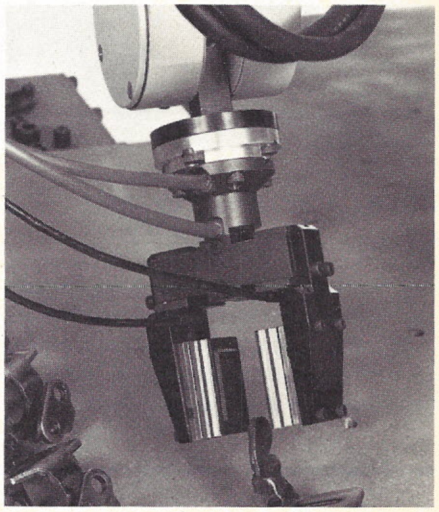
The Maxx-5, a five-axis articulated arm robot, can be mounted on either a bench or an overhead motorized track. The latter configuration saves bench space and permits the robot to service a greater variety of instrument setups. Maximum payload is 3 lb. including gripper. End-of-arm speed is 51 in./sec. with up to a 5 oz. payload and 6 in./sec. with a 3 lb. payload. Reach is 18.4 spherical radius without gripper. A number of accessory modules are available. Control is via an IBM PC with menu-driven software.

For more information, contact: Fisher Scientific, 711 Forbes Ave., Pittsburgh, PA 15219, telephone (412) 562-8468. **Circle 102**

Robotic Workcell Tests Rigid Disks

An off-the-shelf robotic workcell is now available for use in clean room certification of rigid computer disks. The cell integrates an IBM robot equipped with a special kit to service two glide-testers and three magnetic certifiers. Disks are delivered to the workcell in cassettes via two input conveyors. The robot systematically loads the disks onto the glide-height testers and, upon successful completion of testing, transfers the disks to the certifier spindles. The system then sorts the tested disks into one of eight possible quality groupings. Completed disks are off-loaded in cassettes via two output conveyors. The supplier provides the robot and all the software and ancillary equipment.

For more information, contact: Engineered Systems & Development Corp., 600 Meridian Ave., San Jose, CA 95126-3480, telephone (408) 280-5000. **Circle 103**



Tactile Sensors Fit Robot Grippers

A line of tactile sensors, small enough to fit on a gripper and factory-rugged, provides information on patterns of contact, orientation, location, force, and moment. The LTS-200A, a 10×16 array sensor with 0.07 in. spacing between sites, provides gray scale measurement of deflection at each site. The LTS-200V measures forces and moments along and about the three coordinate axes. The two sensors can be used separately or combined. They feature a compliant, very low hysteresis, touch surface with high strength and resistance to tear and abrasion.

For more information, contact: Lord Corp., Industrial Automation Div., 407 Gregson Dr., Cary, NC 27511, telephone (919) 469-2500. **Circle 104**

3-D Vision System Guides Robots

An enhanced 3-D vision system for robotic guidance uses features of a workpiece, such as holes, lines, or edges, to find its 3-D location. The system permits off-line programming and includes as standard features interfacing to any robot, visual location of 3-D position, direct 3-D location of the workpiece in robot coordinates, automatic calibration, image processing to find features under variable lighting conditions, and six-axis robot guidance.

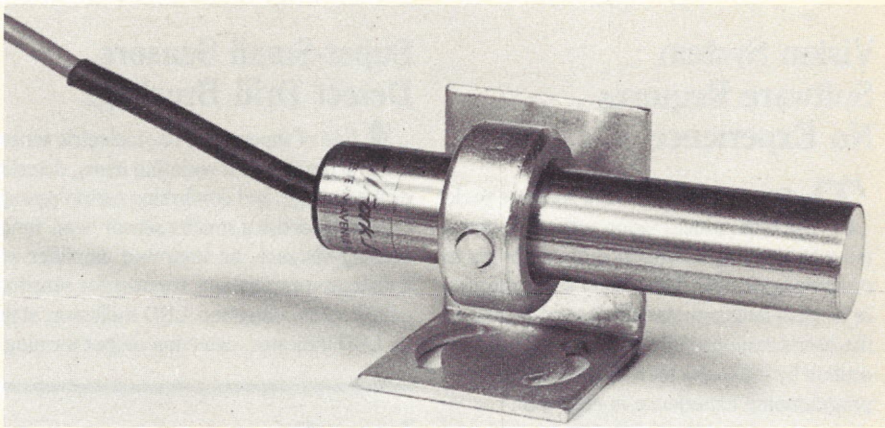
For more information, contact: Machine Vision International Corp., 325 E. Eisenhower Pkwy, Ann Arbor, MI 48104, telephone (313) 996-8033. **Circle 105**

New Products

Proximity Sensors Can Detect Transparent Materials

The 942 and 943 series of ultrasonic proximity sensors can be used to detect the position of any material, including solids, liquids, metallic and nonmetallic surfaces, and substances that are transparent, translucent, or opaque—regardless of color. The 943 is a setpoint version; the 942 offers a choice of digital or analog output. Both are available with remote sensors or as integral units. Applications include workpiece positioning for robots. The 943 has a maximum sensing range of 39 in. without a beam concentrator and up to 47 in. with a concentrator. A rotatable head can provide side sensing in any position over a 360-degree range (removing the head permits sensing from the top of the housing). The 942 sensors can detect targets to within 1 mm over a range of 5.9–59 in. (79 in. with beam deflectors).

For more information, contact: Micro Switch, A Honeywell Div., Freeport, IL 61032, telephone (815) 235-6600. **Circle 106**



Photoelectric Sensor Interfaces Directly with Robots

The MHDS-A photoelectric sensor is a modulated, high-speed, diffuse sensor that operates at up to 30,000 counts/sec. The logic output can interface directly with robotic systems. Features include a modulated IR beam that provides immunity to ambient light, an LED output indicator to aid alignment and indicate output condition, and complementary outputs to make light/dark switches unnecessary.

For more information, contact: FSI/Fork Standards, Inc., 666 Western Ave., Lombard, IL 60148, telephone (312) 932-9380. **Circle 107**

New Products

Vision System Software Requires No Experience

The Pixel Mechanic™ is a software package that reduces vision system programming to entering a sequence of responses to prompts from a PC. The system communicates in English-language statements and translates the user's response into program code for execution by the Inspector Series™. No previous programming experience is required. The vision system records an object to be used as a benchmark, and Pixel Mechanic displays the image on the monitor. With this image, the user can tag key visual characteristics of the object and instruct the system to record that data as correct. Pixel Mechanic can operate on or off line.

For more information, contact: Opcon, 720 80th St. S.W., Everett, WA 98203-6299, telephone (800) 426-9184 or (206) 353-0900. **Circle 108**

Super-Small Sensors Detect Drill Breakage

A line of super-small photoelectric sensors is designed for counting items, detecting drill breakage, and confirming carton passage. New features are a smaller sensor head, longer sensing distance, an improved amplifier with a distance proportional trimmer for sensitivity adjustments, detection LED indicator, stability LED indicator, detection output warning of unstable operation, and an oil-proof sensor cord. Sensing distances are 78.74 in. for through-beam heads, 7.87 in. for diffusion reflective heads, and 0.39 in. at center for definite reflective heads. Response time of the controller unit is 1 ms.

For more information, contact: Keyence Corp. of America, 20610 Manhattan Place, #132, Torrance, CA 90501, telephone (800) 328-2238 or (213) 328-5270 (in California). **Circle 109**

Laser Beam Controls AGVs

Through the use of Lasernet™, automatic guided vehicles can operate without wire guidepaths. The principle is a HeNe laser beam swept across pre-positioned retro-reflector targets to determine distance, angle, and height. Lasernet can also be used in automated storage and retrieval systems to ensure proper alignment between a crane's picking mechanism and material containers. It is controlled by an on-board microprocessor that provides real-time information, updating every 50 ms. Restart after power loss poses no problems, the company says. The standard target is a 4-in. retro-reflector and the system is specified for distances up to 20 ft. The viewing angle is 90 degrees.

For more information, contact: Namco, 7567 Tyler Blvd., Mentor, OH 44060, telephone (800) NAMTECH. **Circle 110**

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NORTHCON in Seattle, Sept. 30-Oct. 2, booth #958

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